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Solar Plasma Physics

C. William Larson

March 1997

Final Report

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Propulsion Directorate
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FOREWORD

The work reported in this final report was performed by Paul S. Erdman, University of Iowa, Professor William C. Stwalley, University of Connecticut, Jeffrey D. Mills and Professor Peter W. Langhoff, Indiana University, Y. H. Choi, S. Venkateswaran and Professor Charles L. Merkle, Pennsylvania State University, and Dr. M. E. Fajardo, Dr. Patrick G. Carrick and M. Cordonnier-DeRose under JON: 2308M3RI with OL-AC PL/RKS at Phillips Laboratory (PL), Edwards AFB CA 93524-7680. OL-AC PL Project Manager was Dr. C. William Larson.

This report has been reviewed and is approved for release and distribution in accordance with the distribution statement on the cover and on the SF Form 298.

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13. ABSTRACT (MAXIMUM 200 WORDS) This final report provides an historical perspective and a summary of the productivity of this project. Twenty-one publications were produced during the 10-year period 1986 to 1996 as conference proceedings, technical reports, Ph.D dissertations and referred papers. The objective of the project was to measure the optical absorptivities in the visible region of the spectrum of alkali metal vapors in hydrogen gas to support the design of a solar powered rocket engine that used the volumetric absorber concept. A high-temperature furnace (2100 K) was fabricated and operated to simulate the absorption zone of the solar powered rocket. Mixtures of alkali metal vapors (lithium and sodium) were introduced into the hot zone as a jet in which the condition of local chemical equilibrium was established. Jet absorptivities were measured as a function of temperature. At temperatures above approximately 2100 K, overall absorption decreased substantially because of dissociation of the dimer molecules, dilithium, disodium and sodium lithium to atoms. At partial pressures of around 0.1 atm, the alkali metal vapors absorbed virtually all the visible incicident light over a 0.3-cm path length.

14. SUBJECT TERMS

optical absorptivity; alkali metal vapors; hydrogen gas; solar; rocket engine; volumetric absorber; dimer molecules; lithium; sodium; aluminum

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INTRODUCTION

Research and development of the solar powered rocket engine was initiated at the United States Air Force (USAF) Operating Location (OL-AC) Phillips Laboratory (PL), Propulsion Directorate, Edwards AFB California, in the early 1980s. By heating hydrogen gas with concentrated solar radiation, a solar powered propulsion system capable of delivering around 1000 sec of specific impulse could be created. This basic research project was initiated to determine the engineering requirements for one advanced absorber/energy converter concept called a volumetric absorber. The efficiency of energy conversion (solar radiation to propellant enthalpy) in the volumetric absorber is substantially larger than simpler flat plate, cylindrical or other black body absorbers because the absorption medium traps energy that would be lost by reradiation.

The objective of this project was to measure the temperature and density-dependent optical absorption properties of alkali metal vapor seedant materials that were mixed with hydrogen gas. Experimental high temperature spectroscopy was carried out with lithium in 1991, with sodium and lithium in 1992, and with lithium and aluminum in 1993. These experiments quantified the engineering requirements for a volumetric solar energy absorber, provided a plethora of new high temperature spectra of metal vapors in hydrogen, and became the basis for parts of two Ph.D dissertations.

RESULTS

The technical details produced during this project are contained in 21 publications listed in the Appendix.

CONCLUSIONS

The measured spectra of lithium and sodium and their mixtures with hydrogen showed that these seedant materials could be used in a volumetric solar absorber and provide solar rocket performances in excess of 1000 sec of specific impulse. The absorption coefficients of the mixtures decreased drastically as the temperature increased from about 1600 to 2100 K, principally because the absorbing species, metal dimer molecules, were dissociated to atoms at higher temperatures. However, the atomic species themselves absorb strongly in the visible. Thus, the mixtures become transparent at higher temperature over the wavelength ranges where dimers absorb intensely at lower temperatures.

APPENDIX

Publications and Presentations on the Solar Plasma Physics Project
1986 to 1996

1986

1. Larson, C.W., *Solar Plasma Propulsion*, AFRPL-TR-85 096, Air Force Rocket Propulsion Laboratory Interim Report, Edwards AFB CA 93524, Mar 1987.

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3. Choi, Y.H., Venkateswaran, S., Merkle, C.L., and Larson, C.W., "Numerical Solution of Low Reynolds Number Flows with Heat Addition, *Proceedings of the Fifth International Conference on Numerical Methods for Thermal Problems*, R.W. Lewis, K. Morgan, and W.G. Habashi, editors, Volume V, Part 2, Montreal, Canada, Jun 29-Jul 3, 1987, pp. 1722-1733.

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1992

7. Erdman, P.S., Stwalley, W.C., Larson, C.W. and Fajardo, M.E., "Optical Absorption of Lithium at Extreme Temperatures and Pressures for Application to Solar Plasma Absorption," *First Annual Conference of the Iowa Space Grant Consortium*, University of Iowa, Iowa City, Iowa, Jan 24-25, 1992.

8. Larson, C.W., Fajardo, M.E., Mills, J.D., Langhoff, P.W., Erdman, P.S., and Stwalley, W.C., "Visible Absorption Spectroscopy of Dense, High Temperature Lithium Vapor," presented at the XXth Informal Conference on Photochemistry, Atlanta, Georgia, Poster III-10, Apr 26-May 1, 1992.

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1993

12. Erdman, P.S., Stwalley, W.C., Larson, C.W., Carrick, P.G., and Cordonnier, M., "High Temperature Absorption Spectroscopy of Alkali Metal Vapors for Application to Solar Plasma Absorption," Second Annual Conference of the Iowa Space Grant Consortium, University of Northern Iowa, Cedar Falls, Iowa, Feb 5-6, 1993.

13. (With J.D. Mills, P.W. Langhoff, P.S. Erdman, and W.C. Stwalley), "Optical Spectroscopy of Metal Vapors," *Bull Am Phys Society*, **XX**, 1993, p. XXXX. Presented at the Meeting of the Division of Atomic, Molecular, and Optical Physics of the American Physical Society, Reno, Nevada, May 16-19,

14. Mills, J.D., Langhoff, P.W., Larson, C.W., Fajardo, M.E., Erdman, P.S., and Stwalley, W.C., "Spectroscopy of Metal Vapors," Ohio State University International Symposium on Molecular Spectroscopy, Ohio State University, Columbus, Ohio, June 14-18, 1993.

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